RESEARCH DEPARTMENT

A programme compressor/limiter using light-controlled variable-loss elements and noise reduction gate

TECHNOLOGICAL REPORT No. L-069

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THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

RESEARCH DEPARTMENT

A PROGRAMME COMPRESSOR/LIMITER USING LIGHT-CONTROLLED VARIABLE-LOSS ELEMENTS AND NOISE REDUCTION GATE

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A PROGRAMME COMPRESSOR/LIMITER USING LIGHT-CONTROLLED VARIABLE-LOSS ELEMENTS AND NOISE REDUCTION GATE

SUMMARY

For experiments on the restriction of the dynamic range of programmes, a combined limiter and 2 : 1 volume compressor has been constructed. Gain variation is effected in each case by varying the light falling on a photoconductive element; fast-acting solid-state light sources are employed. The equipment, which is transistorized and self-contained, also incorporates a gating system to restrict the rise in background noise during programme pauses.

1. INTRODUCTION

In broadcasting, restriction of the volume range of the programme signal is necessary because of the technical limitations of the transmission system; to this end, operating staff are given instructions* to guide them in maintaining the peak levels of a programme within specific upper and lower limits for various types of material while allowing considerable variation in interpretation within these limits in keeping with the artistic requirements of the production. In practice, however, the conditions met with in television and sound broadcasting sometimes make it difficult to fulfil this aim.

The production of programme can be very complex and up to 40 channels on a sound control desk may be employed. In the course of this operation, which may run, after initial rehearsals, to its full length without a break, channel levels varying over a large range have to be closely controlled, sometimes to within limits of 1 to 2 dB. At the same time, the widely varying nature of the programme signal, coupled with the large variety of microphones and techniques used, leads to large differences between the maximum signal levels produced by different performers. In these circumstances, it is difficult at times to avoid, on the one hand, occasional periods of low level signal during which a listener may miss a few words of dialogue, and on the other, occasional bursts of programme so high in level as to produce audible distortion through the overloading of some element in the broadcasting chain.

This situation could clearly be eased by the use of some kind of automatic volume compressor or limiter; while devices of this kind have been used for a number of years by the film and record industries, little published information has appeared concerning their performance and practical application. It was therefore decided to construct an experimental compressor and limiter in which the various parameters should be under accurate control, so that experiments could be carried out both under laboratory conditions and in the studios during actual productions.

The combined compressor and limiter described in this report was used in a series of operational experiments extending over about a year, in the course of which many observations were made on both recorded and live studio productions. The experience gained in this work has helped in specifying** the compressors now scheduled for production by a commercial manufacturer for the BBC.

In designing the compressor and limiter, use was made*** of light-operated gain-regulating devices, consisting of high-speed solid-state light sources in conjunction with photoconductive cells functioning as variable-resistance elements in simple attenuator circuits in the programme chain. This arrangement, in which the programme signal circuits are electrically isolated from the control circuits, is inherently free from "thump" and distortion effects which may occur when the control current enters the signal circuit; in conventional variable-gain devices employing valves or transistors, such effects can be reduced to acceptable proportions only by the use of push-pull circuits maintained in a state of accurate balance. The type of gain-control element employed in the present design readily lends itself to the construction of a compressor in which the compression ratio, i.e. the ratio of corresponding decibel increments of input and output signal, remains constant at 2 : 1 over a wide range of levels. This figure lies at about the middle of the range of compression ratios used in commercial equipment.

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* Control and modulation range instructions, C.P.Ops Transmitters and Studio Centres, April 1960.
Control and modulation range instructions, television, December 1963.

** Limiter/compressor programme amplifier for Pye television sound control desks, P.I.D. Specification No. LF 102.

*** BBC Patent Application No. 46362/64.

The equipment, which is transistorized and mains operated, accepts a wide range of input levels and can be used for simultaneously compressing and limiting the programme signal at sound control positions in use by the BBC.

2. LIGHT-CONTROLLED VARIABLE-LOSS ELEMENTS : DESIGN CONSIDERATIONS

2.1. General

The advantages of using photoconductive devices as variable-loss elements in programme circuits have been recognized for a number of years, and designs for a signal gate[1], a compressor[2] and a limiter[3] operating on this principle have been described in the literature. A particularly attractive feature of a photoconductive gain control system is the electrical isolation of the programme circuit from the control element, which consists of a light source mounted close to the photoconductive cell, from which all extraneous illumination is excluded. The light source generally takes the form of an incandescent lamp, the thermal inertia of which unfortunately introduces a time lag of at least 10 ms to 20 ms, about one order greater than the operating times required in high-quality broadcasting or recording equipment. Moreover, while the conductance of the photoconductive cell may vary linearly with light flux, the sensitivity of such cells varies with the colour temperature of the source, which, in the case of an incandescent lamp, is a function of the operating current; with this type of illumination, therefore, it is difficult to produce a variable-loss device having a simple and predictable relationship between control current and attenuation.

2.2. Solid State Light Sources

Recent developments in semiconductor light sources have, however, made it possible to eliminate some of the defects associated with the earlier photoconductive control devices. With solid state light sources, the light flux produced is proportional to current, while the time lag between the two is of the order of nanoseconds. The wavelength of incoherent light radiated, which remains substantially constant up to high currents, falls typically in a narrow band between 450 nm and 900 nm depending on the materials used and impurities introduced during the manufacturing process.

2.3. Photoconductive Cells

Photoconductive cells can be obtained which behave as nearly pure resistances, even at terminal voltages greater than normal programme signals. Their operating times are in the millisecond region and their conductance varies linearly with the incident light flux falling on the photoconductive surface; the wavelength of maximum sensitivity lies typically in a narrow band between 400 nm and 750 nm.

2.4. Design of Light-Controlled Resistor

The design to be described utilises Gallium Phosphide (GaP) light sources manufactured as alloyed p.n. junctions, which radiate in the visible spectrum at 700 nm with a bandwidth of 70 nm in conjunction with Cadmium Selenide (CdSe) photoconductive cells, which have a narrow peak in spectral sensitivity at approximately the same wavelength. The two devices thus spectrally matched are assembled with their active surfaces about 0·025 mm apart and encapsulated in epoxy resin of high resistivity and low dielectric constant. The resulting four-terminal unit will be referred to for convenience as a light-controlled resistor and abbreviated L.C.R.

The photoconductive cells used were of CdSe material type 3 supplied by the Clairex Corporation of America, with the designation CLX100, while the GaP light-emitting diodes were supplied by Ferranti Ltd as type XP14. A photograph of an experimental encapsulation provided by S.E.R.L., Baldock, is shown in Fig. 1. The final version used and supplied, already encapsulated, by Ferranti Ltd to a BBC specification has a covering preventing the entry of ambient light; Fig. 2 shows the constructional details.

2.5. Properties of Light-Controlled Resistor

2.5.1. Static Characteristics

Fig. 3 shows the relationship between the current through the GaP diode and the conductance of the CdSe cell for a typical L.C.R. and will be seen to be linear over a current range of nearly ten to one. The right-hand scale shows the useful range of resistance to be between approximately 1 MΩ and 30 kΩ. To make the conductance proportional to the control current, an offset current of 1 to 2 mA must be provided; the offset current required depends on the doping process in the manufacture of the light source and is subject to some variation in production. With no current flowing in the light source, the resistance of the cell exceeds 100 MΩ.

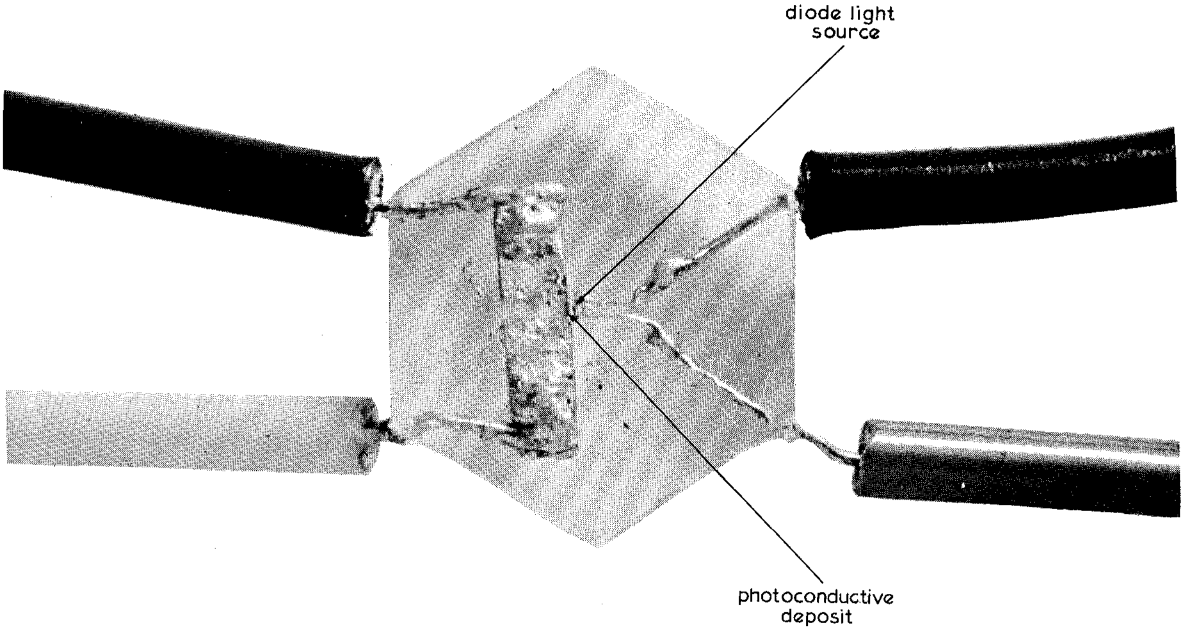


Fig. 1 - Experimental encapsulated GaP diode and CdSe photoconductive cell

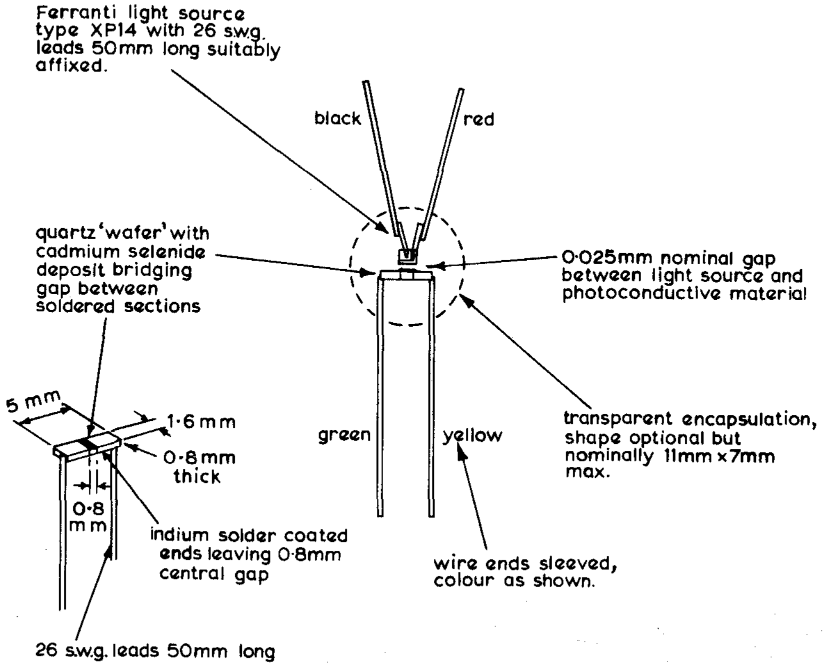

Ferranti light source type XP14 with 26 s.w.g. leads 50mm long suitably affixed.
black
red
quartz 'wafer' with cadmium selenide deposit bridging gap between soldered sections
0·025mm nominal gap between light source and photoconductive material
5 mm
1·6 mm
0·8 mm thick
0·8 mm
green
yellow
transparent encapsulation, shape optional but nominally 11mm x 7mm max.
indium solder coated ends leaving 0·8mm central gap
wire ends sleeved, colour as shown.
26 s.w.g. leads 50mm long

Fig. 2 - Constructional details of light-controlled resistor

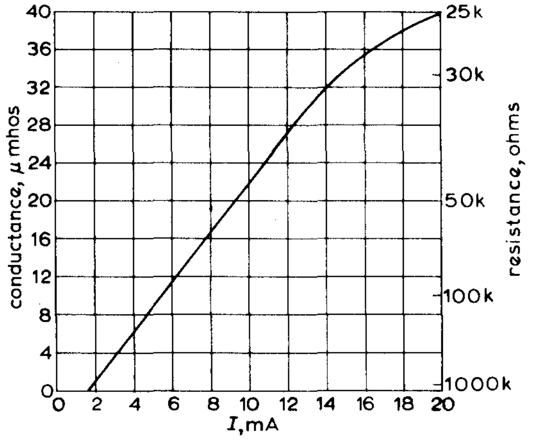


Fig. 3 - Conductance of CdSe cell as function of current through GaP diode

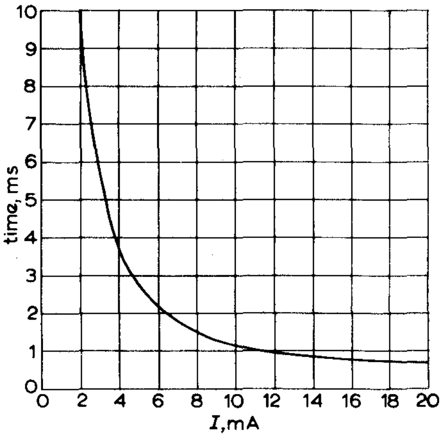


Fig. 4 - Time constant of L.C.R. as function of current through GaP diode

2.5.2. Capacitances

The capacitance between the light diode and photoconductive cell is approximately 0·5 pF, which, for the low circuit impedances concerned, represents a very small coupling between the programme path and control chain. The shunt capacity of the cell is approximately 0·3 pF.

2.5.3. Dynamic Characteristics

Fig. 4 shows the effective time constant of the L.C.R. system, expressed as the time interval after the sudden application of direct current to the GaP diode before the conductivity of the CdSe cell reaches 63% of its final steady-state value. The operating time of the light source is known to be several orders of magnitude shorter than that of the photoconductive cell, so that the latter determines the time response of the system. The time constant is shown as a function of the current flowing through the light source; as with many photo-electric effects, the time lag in the system is reduced as the light intensity increases. The minimum value of time constant obtainable with the present photoconductive material - which is the fastest currently available - is around 1 ms.

2.5.4. Stability

Since the radiated light output of the GaP diodes is a direct function of the junction current, the effects of the temperature-dependent junction voltage can be made negligible by driving the light source from a high impedance circuit.

The operating life of the light-controlled resistor is determined by the ageing of the light source, which in turn depends on the current. Allowing for the fact that the current through the GaP diode rarely reaches the maximum of 20 mA allowing for continuous operation, the time which would elapse before the light intensity falls to one half is estimated from published data to be in excess of 10 000 hours. Circuit adjustments in any case have to be provided to allow for initial differences between individual GaP diodes, and the same facility could provide compensation for ageing. Fortunately the deterioration of a semi-conductor light source is gradual and there is no catastrophic failure as in the case of an incandescent lamp.

2.6. Use of L.C.R. in Compressor/Limiter and Gate Circuits

2.6.1. Operation of Compressor

Fig. 5 shows a simplified diagram of a circuit for obtaining a 2 : 1 compression ratio, i.e. an output/input signal relationship such that increments of output signal amplitude expressed in decibels are half the corresponding increments of input signal amplitude.

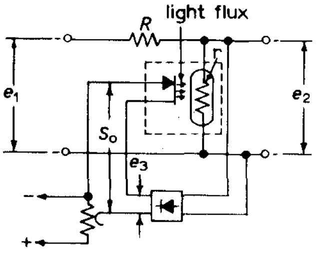


Fig. 5 - Simplified circuit showing action of output-controlled compressor

The signal applied to the control chain is derived from the output signal and in consequence the compressor is said to be output-controlled. For simplicity, the control chain is represented in Fig. 5 by a rectifier symbol, which must be taken to include all the components necessary in a working arrangement. Signal voltages e_1 and e_2 appear respectively at the input and output terminals of an attenuator formed by the fixed series resistor R and the variable photoconductive shunt resistor r. The rectified voltage from the control chain, e_3, is opposed by a reverse bias voltage S_0; the circuit is so arranged that the rectified current flowing in the light source of the L.C.R. is zero when $e_3 < S_0$ and proportional to $e_3 - S_0$ when $e_3 \geqq S_0$. For the latter condition it can readily be shown that if

$$K_1 = \frac{e_3}{e_2} \text{ and } K_2 = 1/[r(e_3 - S_0)]$$

then, by making RK_2S_0 equal to unity, the output/

input relationship for output signal levels greater than S_O/K_1 can be reduced to

$$e_2 = \{e_1/(RK_1K_2)\}^{1/2} \qquad (1)$$

so that on a decibel scale, changes in output level are half of the corresponding changes in input level.

In practice, the requirement that $1/[r(e_3 - S_O)]$ shall be a constant is easily satisfied since the conductance/current relationship of the L.C.R. is substantially linear over the working range.

2.6.2. Operation of Limiter

Fig. 6 shows a simplified diagram of a circuit for obtaining a limiter characteristic, in which e_2 remains constant for values of e_1 exceeding a prescribed level. In this case the signal fed to the control chain is derived from the input signal e_1 and the limiter is therefore said to be input-controlled.

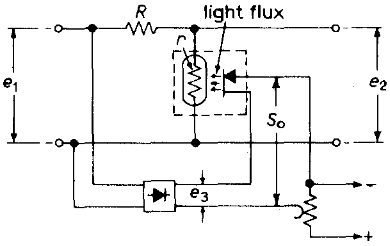


Fig. 6 - Simplified circuit showing action of input-controlled limiter

As in the previous example, RK_1S_O is made equal to unity. It can readily be shown that if $K_1 = e_3/e_1$, then for any input signal having an amplitude greater than S_O/K_1, the amplitude of the corresponding output signal is a constant given by

$$e_2 = 1/(RK_1K_2) \qquad (2)$$

It is possible to construct an output-controlled limiter in which the circuit arrangement is similar to that of Fig. 5, i.e. signals applied to the control chain derived from the output of the variable-loss network; however, the input-controlled version described above is preferred so as to avoid any instability which may arise through the addition of the time lag in the L.C.R. to that already existing in the control chain.

2.6.3. Operation of Gate

To avoid the transmission of unwanted background noises from the studio, it may sometimes be desirable to interrupt the signal circuit automatically whenever the programme level falls below a predetermined value. This function can be conveniently performed by a light-controlled variable resistor connected, as shown in Fig. 7, in series with the signal circuit, the rectified current for the light source being derived from the incoming signal. The gain of the control chain is made so high that a slight increase in signal level above the value required to overcome the bias S_O causes the resistance r of the photoconductive element to be reduced to a negligible figure.

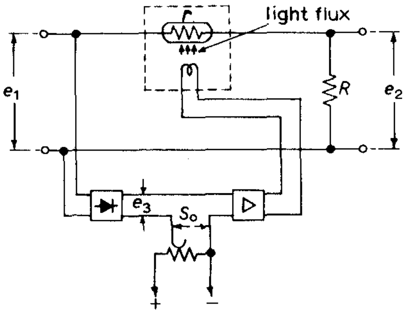


Fig. 7 - Simplified circuit showing action of input-controlled gate

It would in principle be possible to employ the same type of light-controlled resistor in the gate as in the compressor and limiter. For instrumental reasons, however, a commercial* light-controlled resistor employing an incandescent lamp as light source was used for the gate; the operating speed, though much slower than that obtainable with a solid-state light source, was considered adequate for the purpose.

3. GENERAL DESCRIPTION OF EQUIPMENT

Fig. 8 shows a block schematic diagram of the equipment, the various stages of operation being separated by dotted lines. The signal passes successively through an input attenuator and amplifier, noise reduction gate, 2 : 1 compressor, limiter and output amplifier. The gate, compressor and limiter incorporate variable-loss elements LCR1, LCR2 and LCR3 respectively; in each case, the gain regulation is effected through a control chain comprising a signal rectifier to supply current to the L.C.R. light source, together with smoothing circuits which also determine the dynamic characteristics of the system. The control chains of the gate and limiter derive their signals from the inputs of their respective variable-loss stages, while the control chain of the compressor is supplied from the output of its variable-loss stage after a buffer amplifier.

The equipment is designed to give an output of up to 0 dBm**programme volume and by adjustment of the input attenuator it can be made to accept any input programme volume in the range 0 dBm to -60 dBm. A built-in programme meter, the design of which is based on that of the standard instrument ME12/5, can be switched to monitor the signal from either the input or the output amplifier.

Signals from the input amplifier are applied to the noise reduction gate, which allows programme to pass only when the level exceeds a preset threshold value.*** The gate is bypassed by an attenuator, the setting of which determines the circuit loss for signals below the threshold level. The overall effect of the gating circuit is to produce a step in the overall output/input characteristic of the system; the attenuator, which serves to regulate

* Raytheon Raysistor type CK 1121.

** decibels relative to 1 mW.

*** Sometimes known to operators as the "knee" or "breakaway point" of the output/input characteristic.

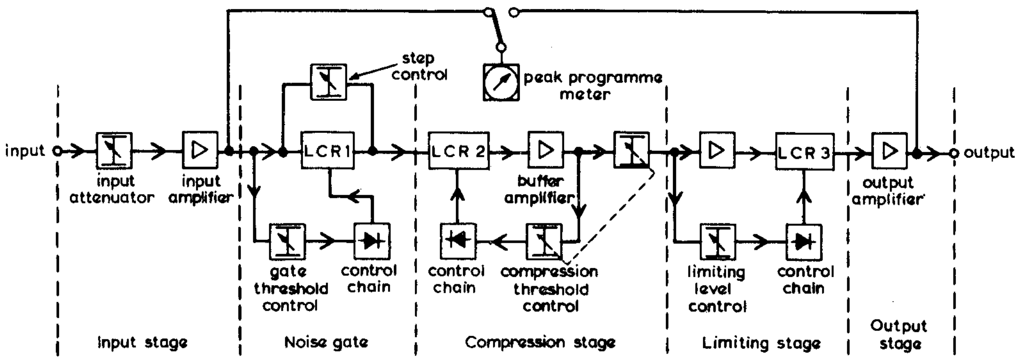


Fig. 8 - Block schematic diagram

the height of this step, is therefore designated "step control". The attenuation provided by the step control can be adjusted to offset the rise in gain of the compressor during pauses in the programme; alternatively, with the step attenuator set at "infinity", an almost silent background can be obtained, though this procedure requires care in adjusting the gating level to avoid suppressing the quietest passages of the transmission or clipping the initial syllables of words.

The compression stage comes into operation when the programme signal level exceeds a threshold value which can be pre-set by adjustment of an attenuator at the input to the control chain. It may be desirable to prevent the average level of the outgoing compressed signal from changing whenever the threshold is changed, and to this end, provision is made to introduce at the output of the compressor an attenuator similar to that at the input to the control chain and mechanically ganged to it. It should be noted that this compensation is only possible because the compression ratio remains substantially constant over the working range.

Signals from the compressor are applied to the limiter stage, the limiting level of which can be adjusted by an attenuator at the input to the control chain, and thence to the output amplifier.

Fig. 9 shows a photograph of the equipment, which includes a twin meter assembly showing the degree of gain reduction in the compressor and limiter stages respectively. For both of the gain reduction meters, a fast-acting movement of the programme-meter type was utilised, as with rapidly fluctuating signal levels, general-purpose meters were found to give misleading indications.

The operation of the gate, compressor and limiter control systems will now be described in detail; reference may be made to Fig. 10 for the complete circuit.

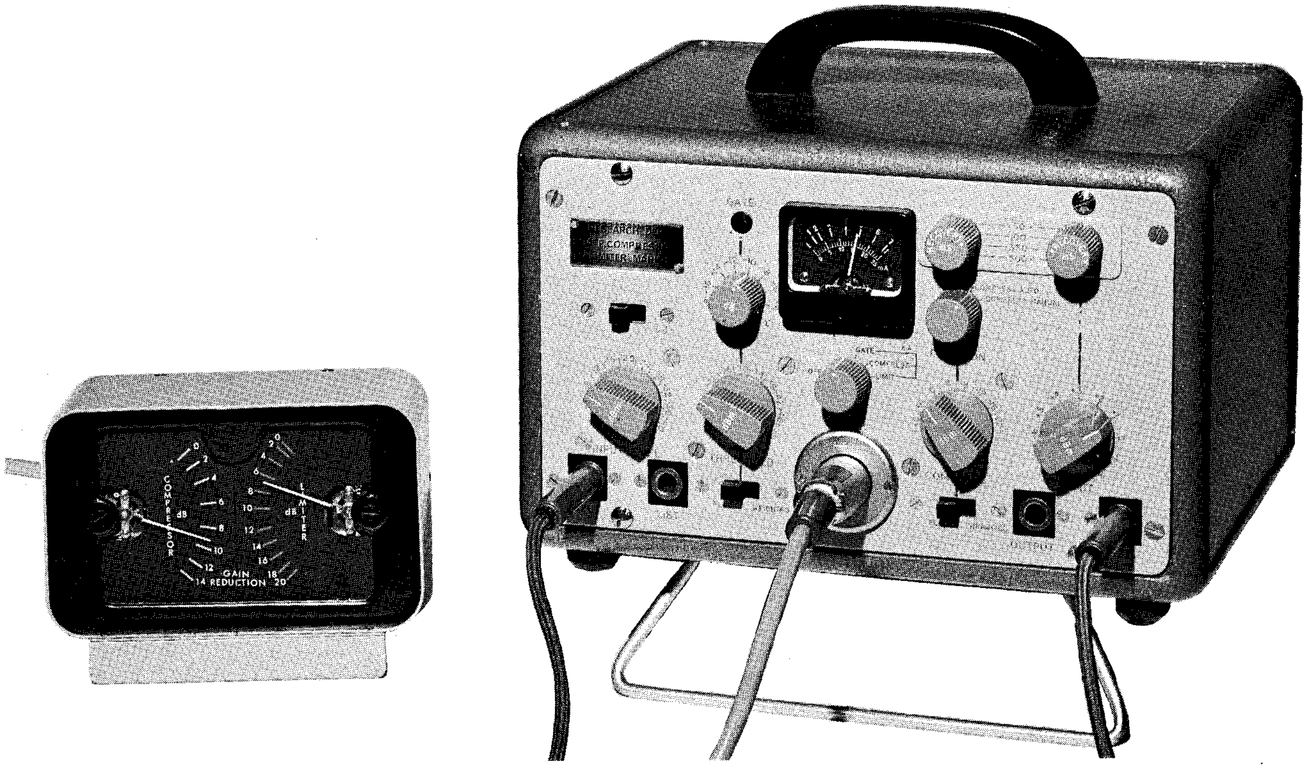
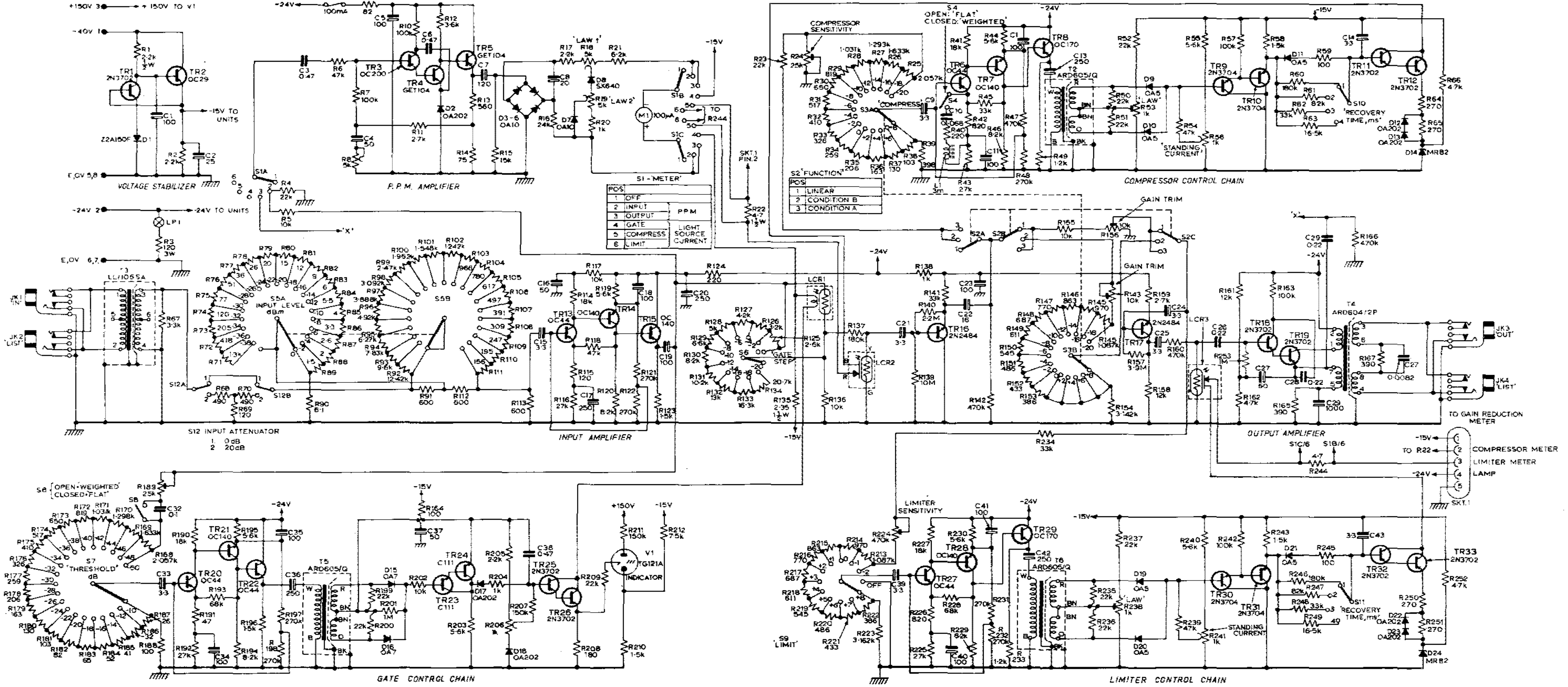


Fig. 9 - View of equipment showing double movement gain reduction meter



THE TOLERANCE ON RESISTORS USED IN SWITCHED ATTENUATORS IS ± 2% OF THE NOMINAL VALUES SHOWN.

Fig. 10 - Circuit diagram

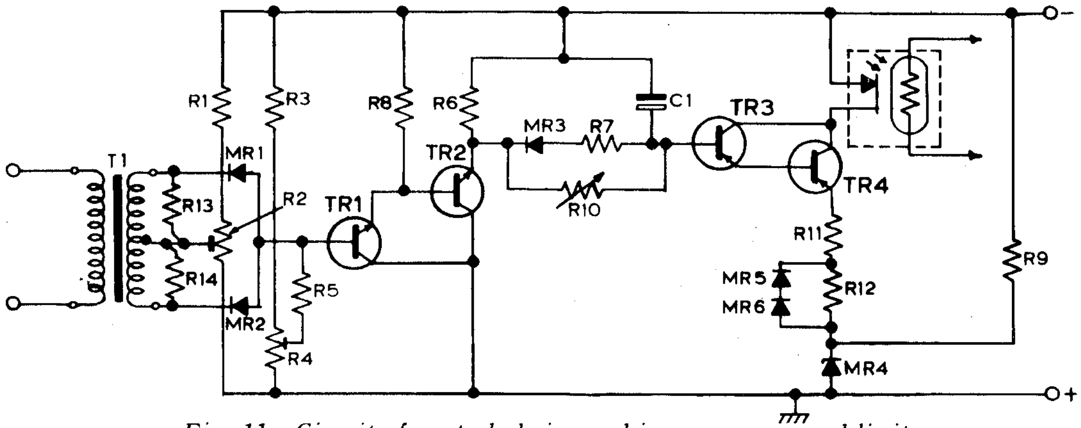


Fig. 11 - Circuit of control chain used in compressor and limiter

4. CONTROL CHAINS

4.1. Compressor and Limiter

4.1.1. Circuit Details

Fig. 11 shows the control chain for the compressor; that of the limiter is identical. The input signal is applied through transformer T1 to full wave rectifiers MR1 and MR2; these are reverse-biassed by a voltage derived from R2, so that they conduct only at signal levels above the prescribed threshold of compression or limiting. The npn transistors TR1 and TR2 form a buffer stage producing signals which, rectified by MR3 and applied to the pnp transistors TR3 and TR4, control the current flowing through the GaP diode of the L.C.R.

For signal levels below the threshold of compression or limiting, TR1 is biassed in the conducting direction and the resulting voltage drop across R6 charges C1; in these circumstances, a current of 1 to 2 mA passes through the GaP diode, producing a small amount of light and bringing the variable-loss element to the threshold of operation as shown in Fig. 3. The combination of the npn and pnp emitter-coupled transistors maintains a high degree of thermal stability (better than 5 parts in 10^6/°C) in the current supplied to the GaP diode.

When the peak value of the signal voltage on the secondary of T1 exceeds the reverse bias voltage applied to MR1 and MR2, the difference appears in the form of negative pulses at the emitter of TR2. This causes C1 to discharge through MR3, R6 and R7, and the current from TR3 and TR4 passing through the GaP diode then increases by an amount proportional to the amplitude of the pulses applied to TR2. The charging time constant of C1, on which the attack characteristic of the limiter or compressor depends, is determined principally by the value of R7. The recovery characteristic depends on the time taken for C1 to recharge after the signal has fallen below the threshold of limiting or compression, and is determined by R10.

It will be noted that the charge-discharge cycle of C1 differs from the corresponding process in a conventional limiter or compressor in that the rapid gain reduction on arrival of a signal is produced by discharging the capacitor while the relatively slow gain recovery on cessation of the signal is brought about by recharging.

The value of R11 is chosen to prevent damage to the light source under maximum signal conditions.

4.1.2. Frequency Weighting

A fast-acting volume compressor has a natural tendency to exaggerate the level of the weaker speech sounds, such as initial sibilants. This effect has long been known to the film industry, and while rigorous correction is clearly impossible, it is usual to employ a palliative device (known, for obvious reasons as a "de-esser") consisting of a high-frequency pre-emphasis circuit introduced into the control chain of the compressor. It was therefore thought advisable to make provision for similar weighting in the present design. Fig. 12 shows the form of weighting employed; this was initially based on current commercial practice but subsequently modified in the light of experiment. The pre-emphasis can be introduced into the compressor control circuit when required by the operation of the switch S4.

4.2. Gate

4.2.1. Circuit Details

Fig. 13 shows the circuit of the control chain for the gate; this differs somewhat from the circuit shown in Fig. 11. The control chain is actuated whenever the amplitudes of the positive pulses from MR1 and MR2 are sufficient to cause TR1 and TR2 to conduct. The resulting amplified pulses at the collector of TR2 discharge C1 through MR3 and R4; the resulting change in voltage across C1 increases the current supplied by TR4 to the light source, which, as previously mentioned, is in this case a small incandescent lamp. The constants of the circuit are such that the gate can be switched from the closed to the fully open condition by an increase of only 1 dB in the amplitude of the control chain input.

The value of R8 is chosen to prevent damage to the lamp under maximum signal conditions.

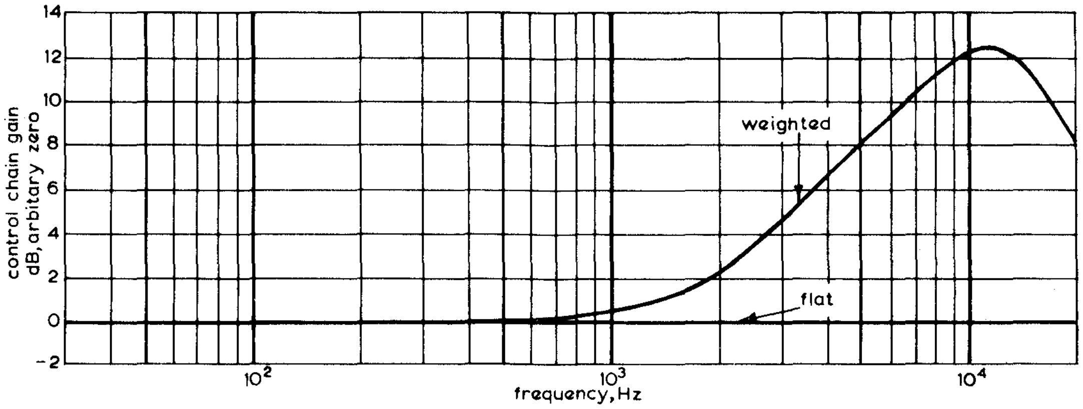


Fig. 12 - Compressor control chain frequency characteristics

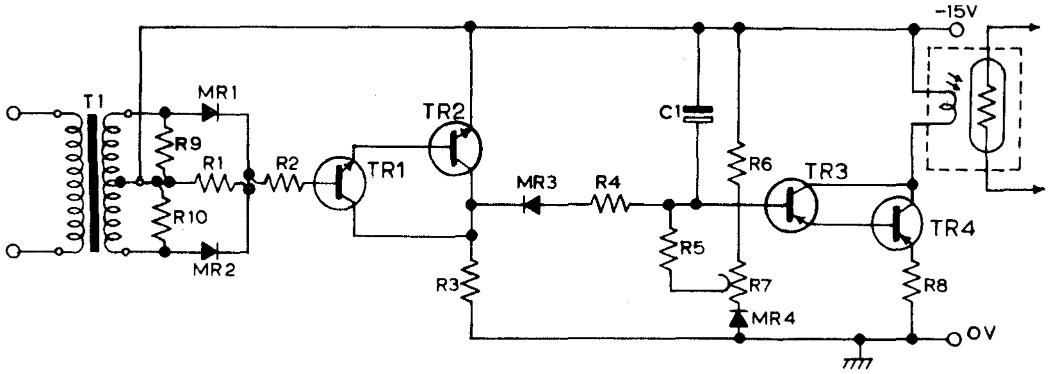


Fig. 13 - Circuit of gate control chain

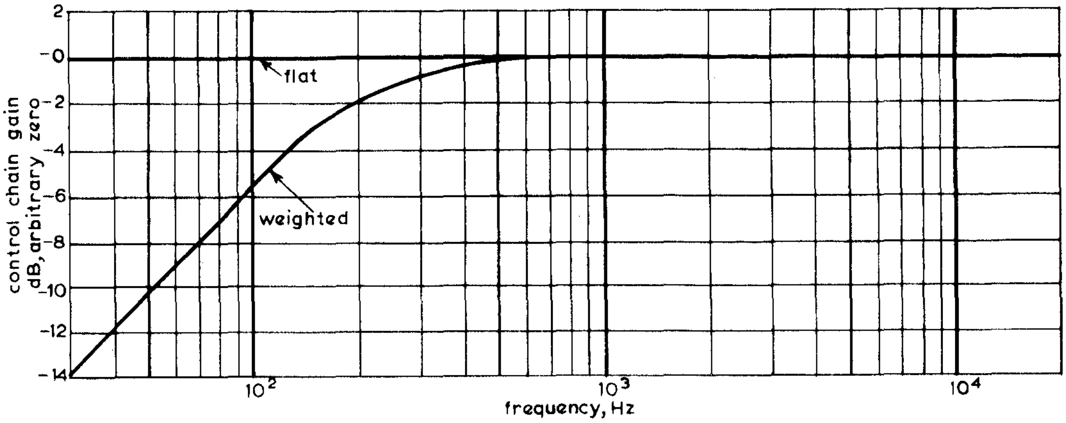


Fig. 14 - Gate control chain frequency characteristics

4.2.2. Frequency Weighting

Ambient noise in the studio may in some cases cause the gate to open during nominally silent periods. Much of this noise occurs at the lower end of the frequency range and it is frequently possible to reduce its effect by appropriate bass attenuation in the control chain with little detriment to the gating action on programme. In the present design, therefore, provision is made for weighting the frequency characteristic of the gate control as shown in Fig. 14; the low-frequency attenuation can be introduced or removed as required by operation of the switch S8.

5. OUTPUT/INPUT CHARACTERISTICS

5.1. Compressor

Fig. 15 shows the output/input characteristic of the compressor measured with the compression threshold set at -20 dBm input level and the overall gain adjusted to be zero at 0 dBm. For operational convenience, the settings of the various control knobs are marked in terms of the stylized set of output/input curves of Fig. 16, which cover a wide range of operating conditions.

A choice between two types of compression characteristic is available by the operation of the "Function Selector" switch S2, the alternative positions of which are for reference purposes designated "A" and "B". With the switch in position "A", gain reduction normally accompanying compression action reduces the output signal accordingly. This has the effect, not only of reducing the range of the signal components into half their decibel value, but of reducing the mean level of the signal as well.

When switch S2 is in position "B", the loss of mean level occurring in condition "A" is compensated at the output, as previously indicated, by mechanical coupling between the programme signal attenuator S3B and the compression threshold attenuator S3A; because the compression ratio is 2 : 1, each 2 dB step of S3A is accompanied by a 1 dB step in S3B.

Fig. 17 illustrates the difference between the "A" and "B" conditions in the case of a hypothetical signal which is already being compressed. When the threshold level is altered by "Y" dB from P_1 to P_2, the fluctuations in signal amplitude are reduced to half their original decibel range in both the "A" and "B" conditions. In condition "A", however, the mean value of the signal has been reduced by $Y/2$ dB whereas in condition "B" the mean value has remained unchanged.

The compression threshold is adjustable in 2 dB steps by the attenuator S3 from +8 dB to -20 dB with respect to normal programme volumes.

5.2. Limiter

Fig. 18 shows the output/input characteristic of the limiter; it should be noted that the functions of the compressor and limiter are separate and are capable of being adjusted independently of each other. The level at which limiting can be made to occur is adjustable in 1 dB steps, by the operation of S9, from +8 dB to -2 dB with respect to the output signal level.

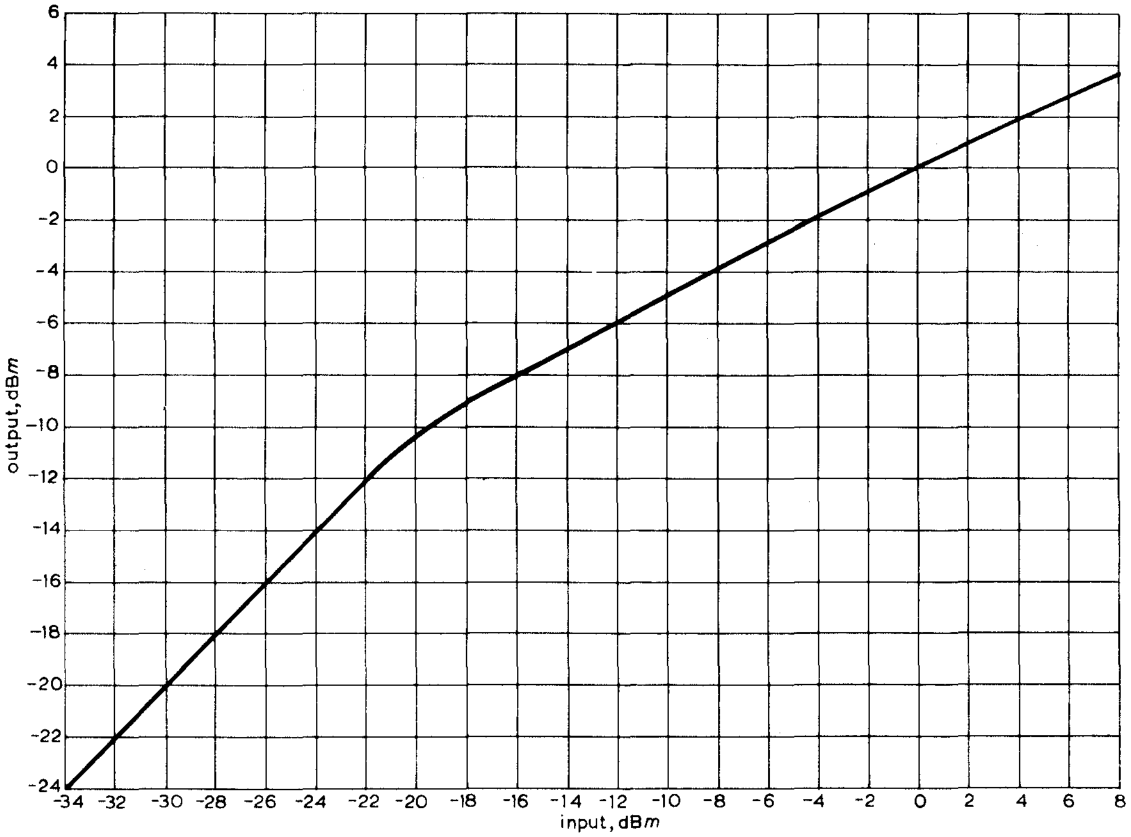


Fig. 15 - Measured output-input signal characteristic of compressor

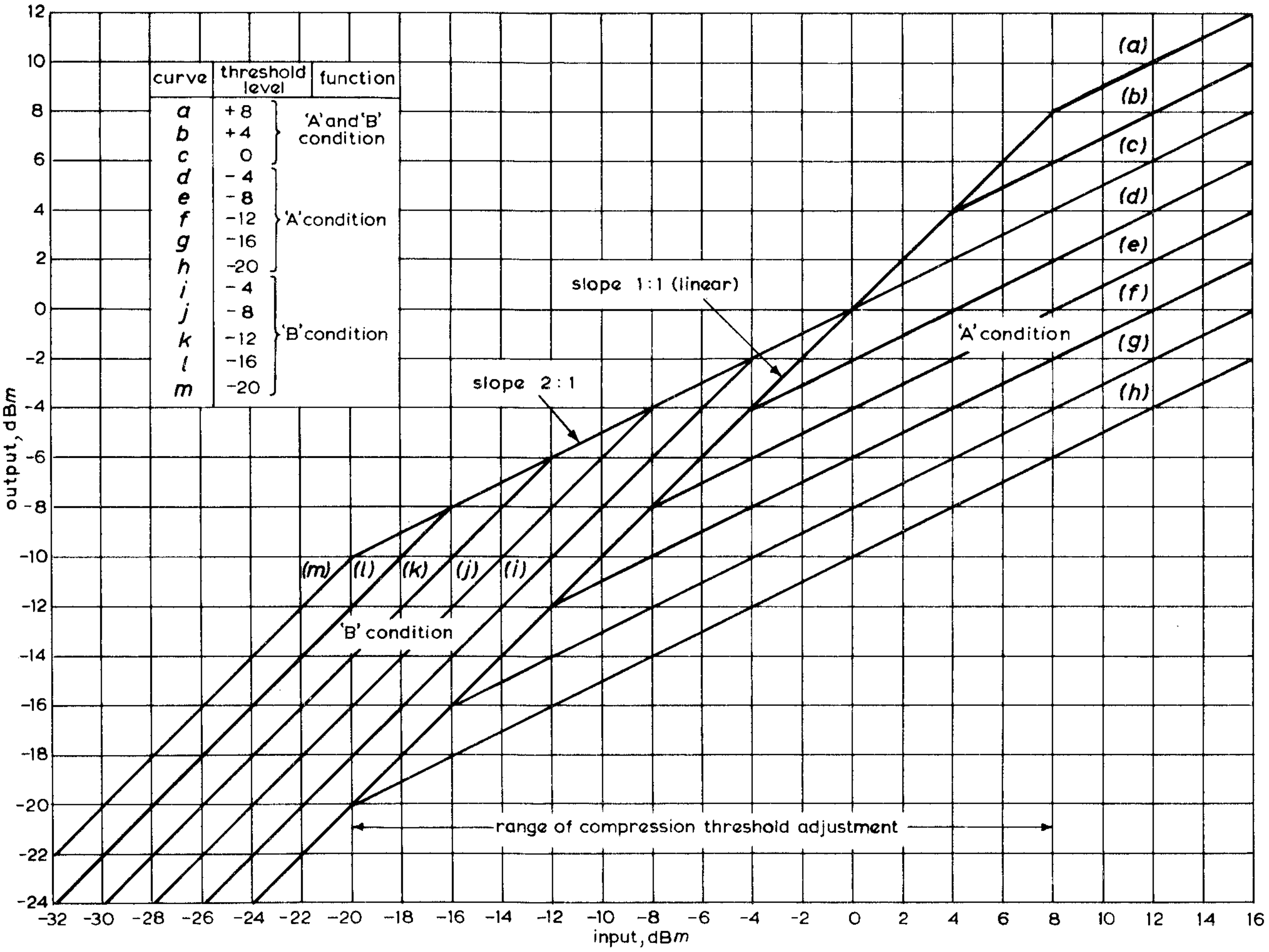


Fig. 16 - Stylized output-input signal characteristics of compressor for various settings of threshold control

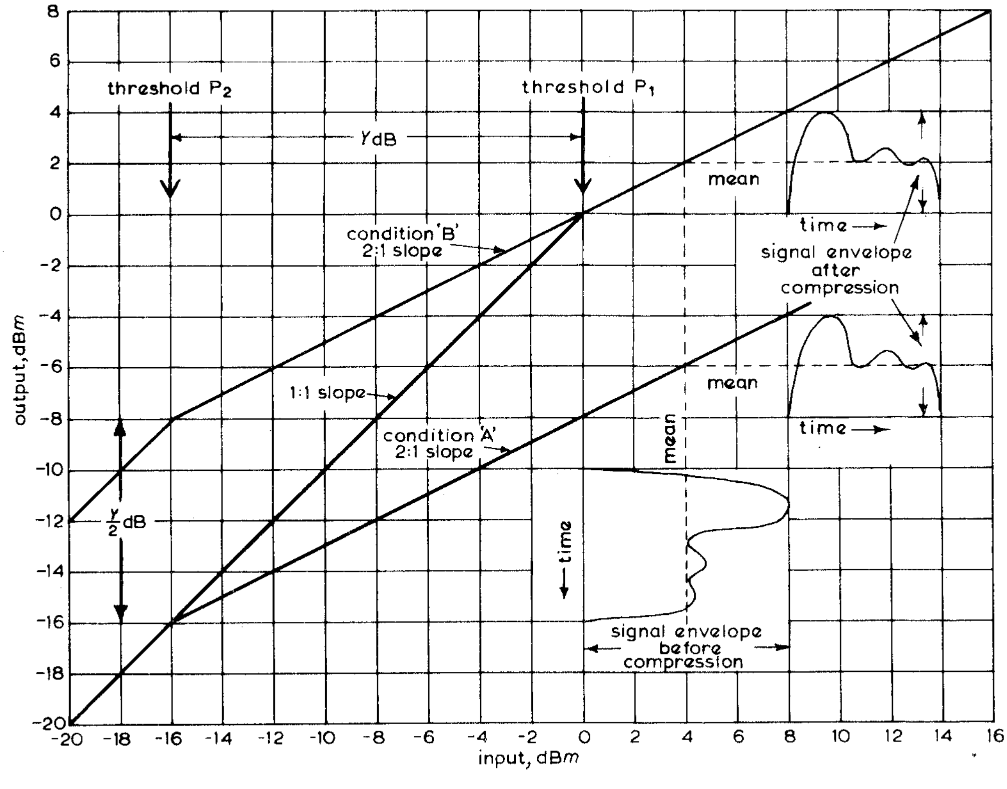


Fig. 17 - The effect of "A" and "B" conditions on a hypothetical signal

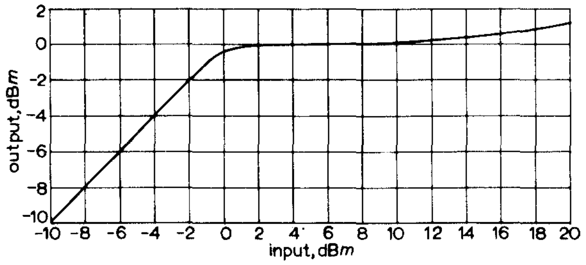


Fig. 18 - Measured output-input signal characteristics of limiter

6. CONCLUSION

The instrument described in this report has been employed for experiments carried out in television and sound broadcasting studios to obtain design information for future equipment; it is at present in use as a laboratory tool in various investigations in which a combined compressor and limiter having a wide range of adjustment is required.

The light-operated variable-gain elements developed have response times in the region of 1 ms, an order or so faster than in some commercial types. For future experiments on compressors and limiters, however, attack times as short as 100 μs may be desirable. The present limitation on speed is set by the photoconductive material available, but it is thought likely that this situation will be remedied in the near future.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

1. MARTENS, A. 1962. Noise-free keying circuit. Electronics, 1962, **35**, March 30, p. 53.
2. HUDAK, J. 1963. Transistorized audio A.G.C. amplifier. *I.E.E.E. Trans.Bcast.*, 1963, **BC-9**, 1, pp. 26 - 30.
3. LAWRENCE, J.F. 1964. An improved method of audio level control for broadcasting and recording. *J.Soc.Motion Pict.Telev.Engrs.*, 1964, **73**, 8, pp. 661 - 663.
4. FRAYNE, J.G. *and* WOLFE, H. 1949. Elements of sound recording. New York, John Wiley, 1949, Chapter 10, p. 173.

APPENDIX

Performance Specification of Optical Compressor/Limiter

GENERAL

Impedances:

Input	600 ohms ±5%)	Balanced
Output	600 ohms ±5%)	

Operating Levels:

Input normal	- 60 to 0 dBm
Input maximum	+28 dBm
Output normal	0 dBm
Output maximum	+16 dBm

Power Requirements:

To unit	24 volts d.c.	340 mA
	150 volts d.c.	1 mA

To power supply 200 to 250 volts 50 Hz mains 23 V.A.

Size:

Width	241 mm
Height	152 mm
Depth	210 mm

Weight:

Unit	4·2 kg
Power supply	2·4 kg

STATIC CHARACTERISTICS

Gain:

Unity to 60 dB in 2 dB steps (uncompressed).

Frequency Response:

± 0·2 dB 30 Hz to 20 kHz between 600 ohm impedances.

Distortion:

At 1 kHz normal output level

0 dBm 0·1% 2nd harmonic
+8 dBm 0·2% 2nd harmonic
+16 dBm 1·5% 2nd and 3rd harmonic

Noise:

dB with respect to output level of +8 dBm measured with P.P.M.

Flat	-73 dB
A.S.N. weighted	-74 dB

DYNAMIC CHARACTERISTICS

	Attack time[*] ms	Recovery time[**] ms
Gate	20	100
Compressor) Limiter)	Approx. 1·5 ms; varies with degree of gain reduction	50, 100, 250 and 500

CONTROL ADJUSTMENTS

Input Level Control:

Adjustable in 2 dB steps over a range of 60 dB.

Gate Threshold:

Adjustable from -10 dBm to -50 dBm in 2 dB steps relative to normal programme level with differential sensitivity of 1 dB.

Gate Step Attenuation:

Overriding gate step attenuation in 2 dB steps from 0 to -20 dB and -60 dB on the last step.

Compression:

Threshold ("knee" or "breakaway") range adjustable from +8 dBm, to -20 dBm relative to normal programme level. Input/output law above threshold: 2 : 1 dB.

Limiting:

Limiting of output level adjustable in 1 dB steps from +8 dBm to -2 dBm.

Weighting:

Gate control chain weighting is available as an alternative to the normally flat frequency response, reducing the gate sensitivity at low frequencies.

Pre-emphasis ("de-essing") is available in the compressor control chain as an alternative to the normally flat frequency response.

Function Selector:

Immediate comparison between compressed and uncompressed programme is available between the "compress" and "linear" positions of the function switch.

A choice between the normal programme signal loss due to compression and having the loss corrected to the normal levels is available on the "A" and "B" position respectively of the function switch.

Metering:

A peak programme meter can be switched to check the input and output levels and be switched to check the control currents of the light sources in the variable-gain elements.

Gain Reduction Indicator:

A twin-movement meter displays gain reduction due to compression and limiting separately and is connected to the mains unit by plug and cable.

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[*] Measured as time taken, after the sudden application of a 10 kHz tone input 12 dB above the limiting level, for the initial overshoot of output signal voltage to be halved.

[**] Measured as the time taken, after removal of the above test signal, for the voltage gain reduction to be halved.

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